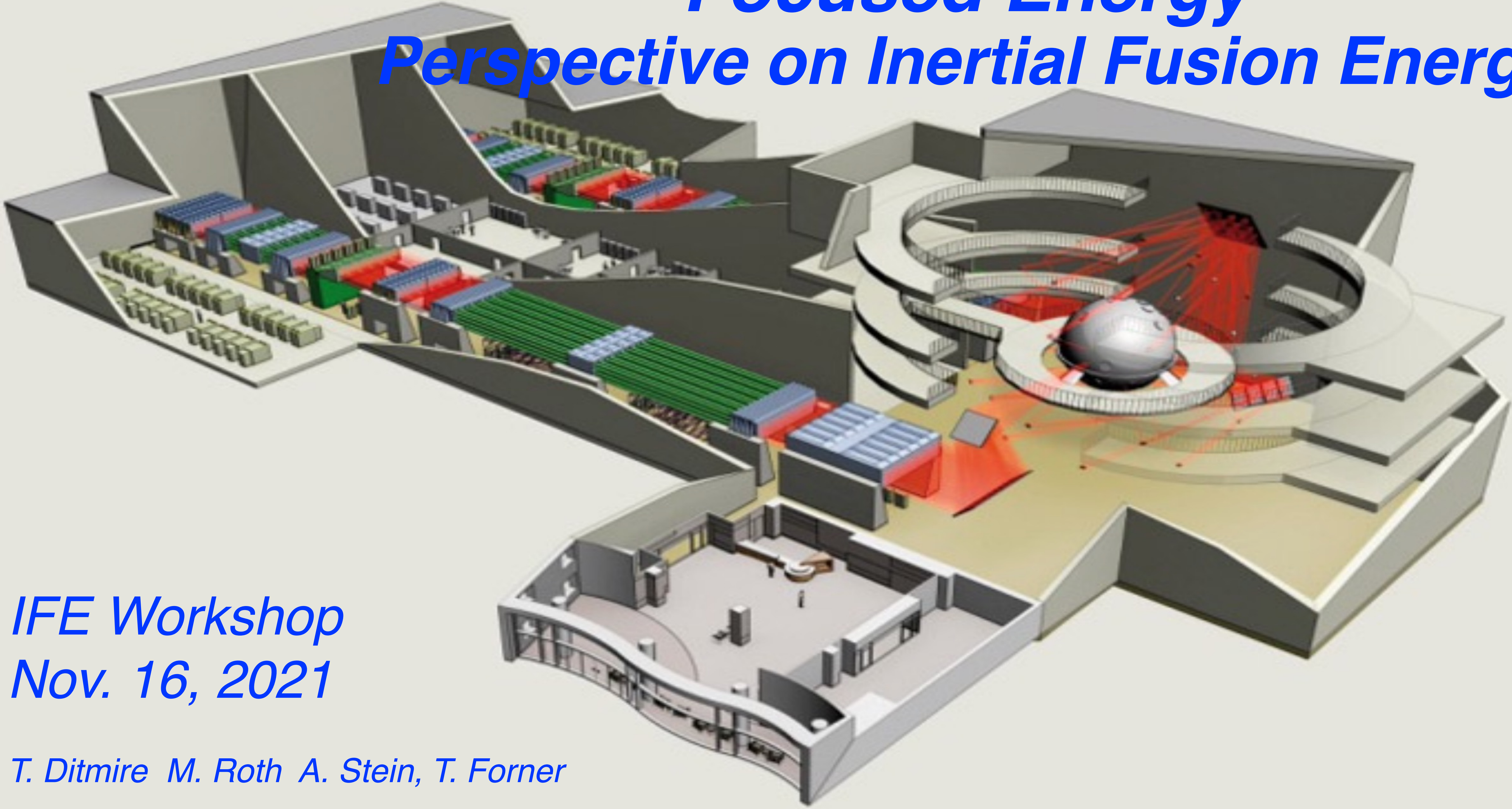
Focused Energy
Perspective on Inertial Fusion Energy



IFE Workshop
Nov. 16, 2021

T. Ditmire M. Roth A. Stein, T. Forner

Focused Energy has been founded in July 2021 and we have assembled a team of consultants and an advisory council

Prof. Dr. Todd Ditmire
Chief Technology Officer
Professor UT Austin, TX
Founder of National Energetics

Prof. Dr. Markus Roth
Chief Science Officer
Professor TU Darmstadt, GER
Founder: IC for nuclear Photonics

Thomas Forner
Chief Executive Officer
Management of a number of high-tech Start-upcompanies

Dr. Anika Stein
Chief Operations Officer
Previously thyssenKrupp Marine Systems

Focused Energy Science and Technology Advisory Council

- *Kurt Schoenberg (Chair, LANL, TU-Darmstadt)*
- *Ricardo Betti (University of Rochester)*
- *Vladimir Tikhonchuk (ELI – BL Prague)*
- *Peter Norreys (U. of Oxford)*
- *Stefano Atzeni (Uni. La Sapenzia, Rome)*

Presently have 12 employees

- **Goal is to ramp to 22 employees by end of 2021**
- **Will ramp to ~ 40 staff by summer 2022**

There have been a number of key advances in recent years that make commercial development of laser-driven IFE timely

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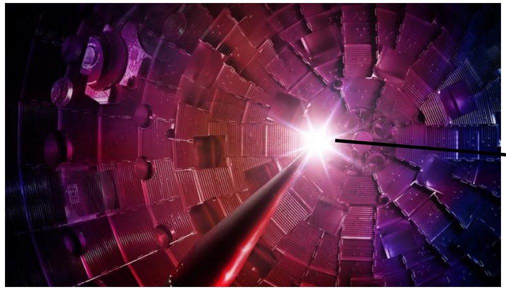
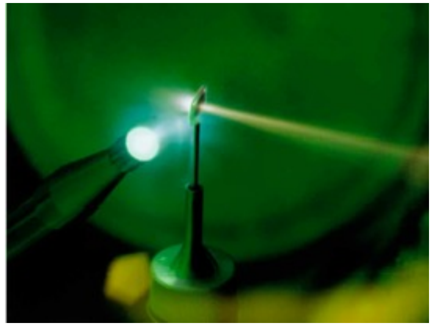
Advances in ICF physics and technology understanding

The National Ignition Facility has made considerable progress in understanding hot-spot ICF



NIF has produced >1.3 MJ of fusion yield on a shot – 70% conversion of laser energy to fusion energy

Very high efficiency in laser driven proton sources has been experimentally observed



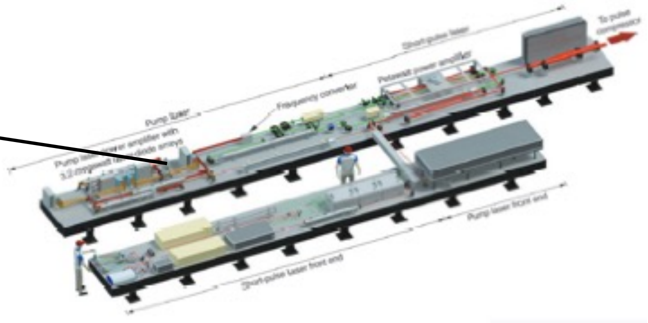
More than 10% of picosecond laser pulse energy has been converted to a proton burst

New techniques for fabricating cone-in-shell PFI targets

Advances in high energy laser technology

Lasers with many hundreds of Joules of energy operating at 10 Hz can now be constructed

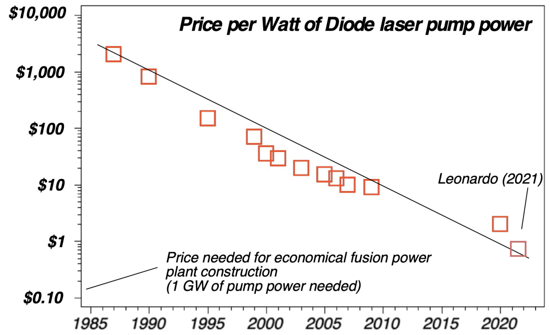
100 J pulsed laser operating at 10 Hz have been fielded



Multi-PW lasers have now been built and can be commercially obtained

Rep. rated kJ class sub-picosecond 10 PW laser has been deployed at ELI in Prague

Diode laser prices have dropped <$1/W



We are developing a technical plan to commercialize IFE by the mid 2030s, with a goal of attempting ignition by the end of the decade

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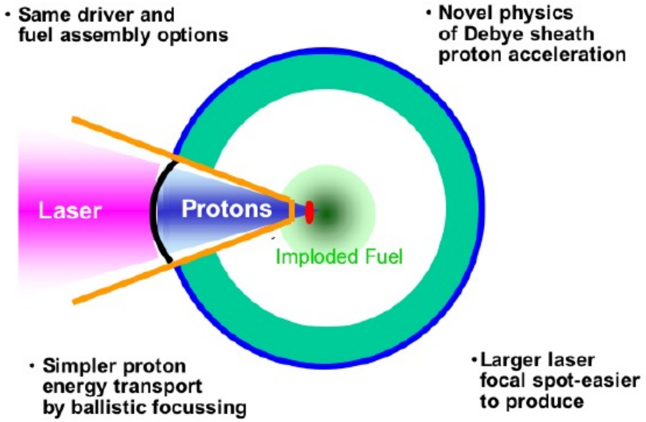
• Basic approach chosen is to utilize direct drive implosion with 2ω light and ignite by proton fast ignition



IFE Phase 1: Test facility and studies

IFE Phase 2: SUPER -NOVA facility. *Ignition*

IFE Phase 3a: QUASAR Diode-pumped power plant demo

IFE Phase 3b: High gain

IFE Phase 3c: Power demo

IFE Power plant deployment

Study most important physics
→ Hydro- eff. and LPI control with 2ω drive
→ proton acceleration with multiple PW beams (10% efficiency goal)

Study integrated compression/proton heating
→ Cryo-targets
→ proton acceleration with cone-in-shell target

IFE R&D
• 10 Hz diode-pumped Laser module devel
• Mass production target fab
• First wall materials and reactor design

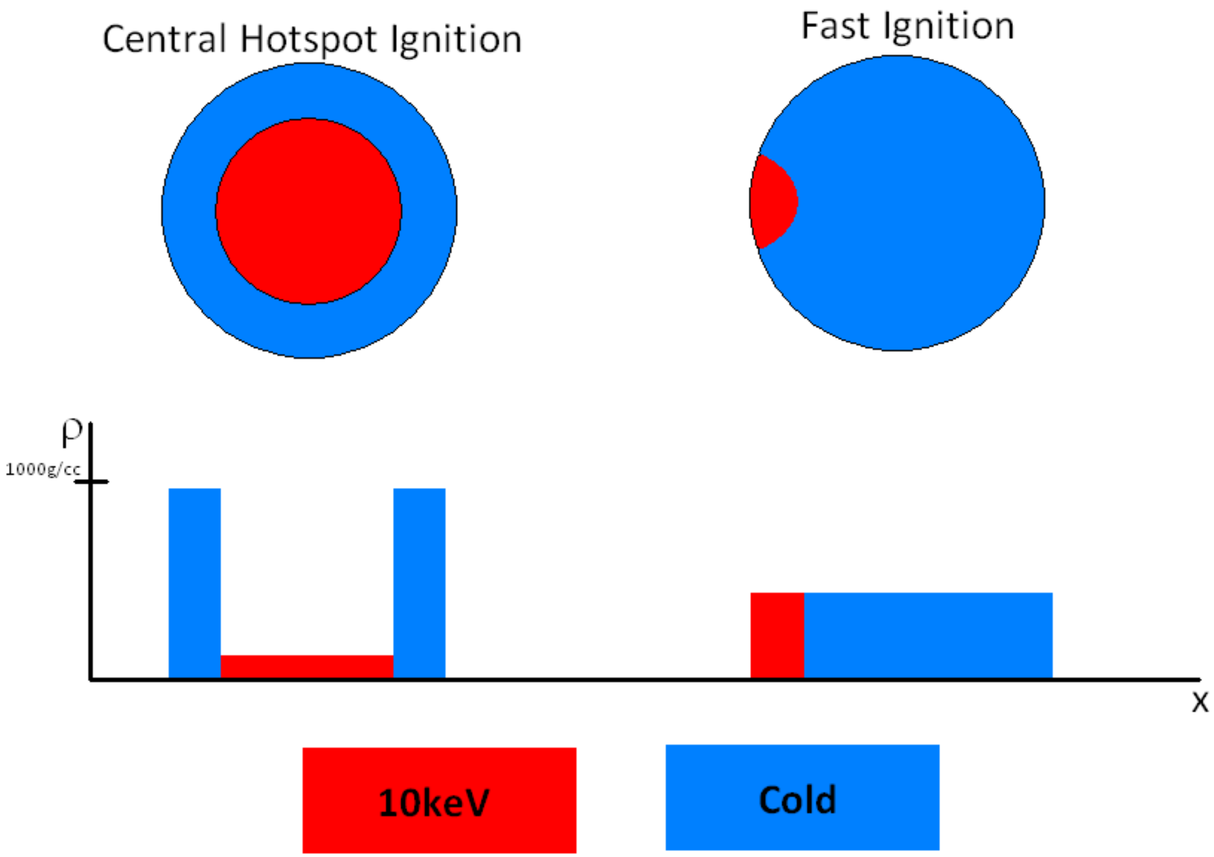
Rep-rated power plant development

Experimental proof of the scaling behavior of our approach | Way to ignition and self-sustaining combustion | Capital market

2021 2022 2023 2024 2026 2028 2030 2035 2040

Proton Fast Ignition ignites compressed fusion fuel by producing a hot spot on the edge of the fuel with a proton pulse

Difference between hot spot and fast ignition

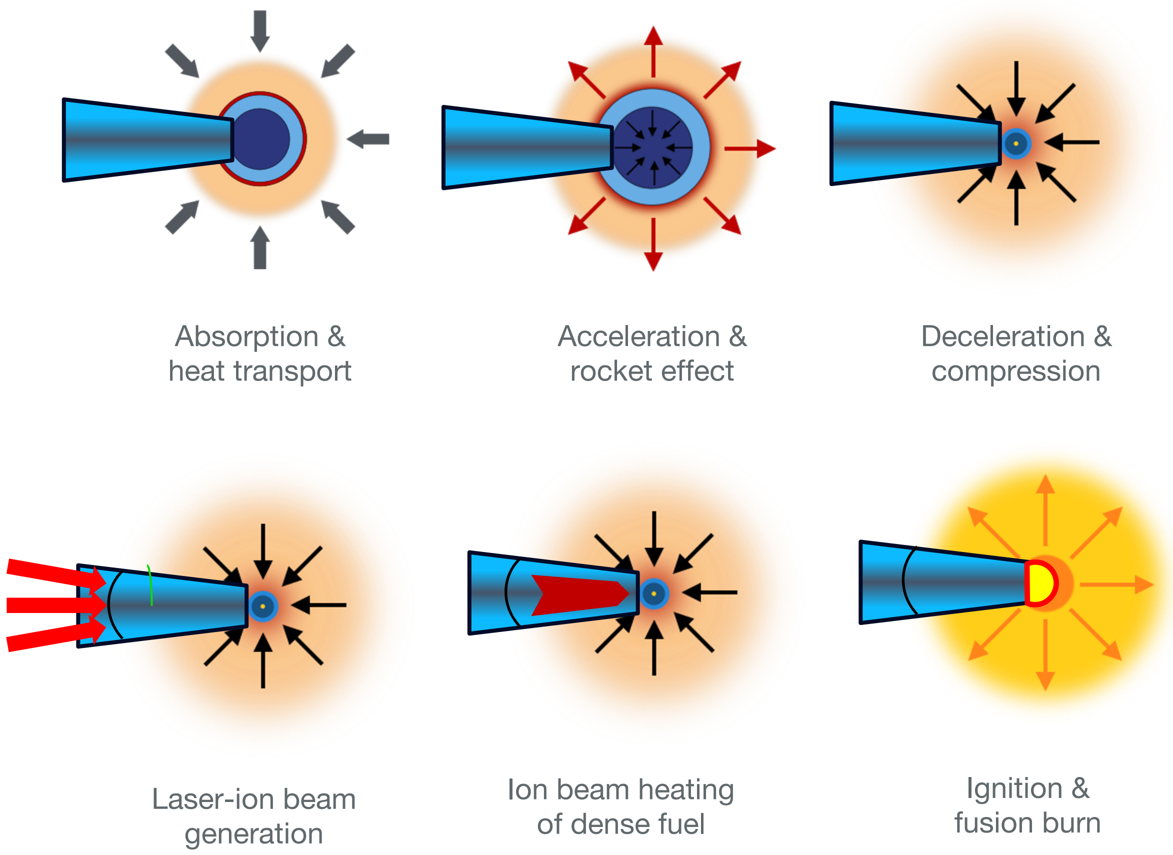


Fast ignition (FI) fuel assemblies differ from their central hot spot (CHS) counterparts

- Fuel is isochoric (by which we mean all at the same density)
- Ignition takes place in denser fuel
- Ignition takes place at the edge of the fuel
- Burn propagates from one side of the fuel to the other, rather than from the centre outwards

Proton Fast Ignition in our approach will employ a cone in shell target

Combining direct-drive laser fuel compression with proton fast ignition to generate a commercially attractive path to harvest energy

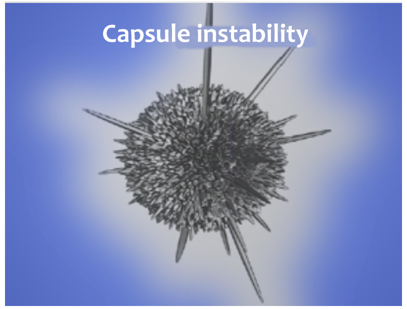


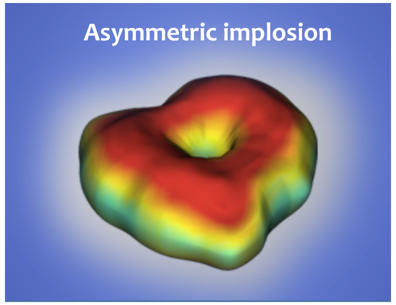
Direct-drive, proton fast ignition using a cone-guided capsule:

- Better energy coupling
- Applicable to fusion energy
- Uses higher efficient green light
- Less sensitive to instabilities
- Higher fusion gain
- Capsule protection in a power plant

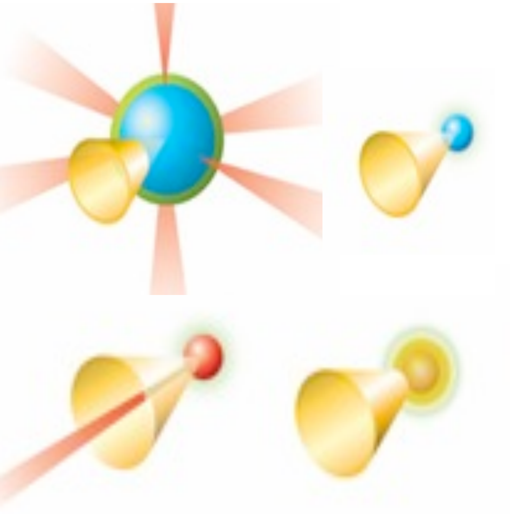
The Fast Ignition approach decouples the implosion of fusion fuel by long pulse lasers from the sparking of ignition in that fuel

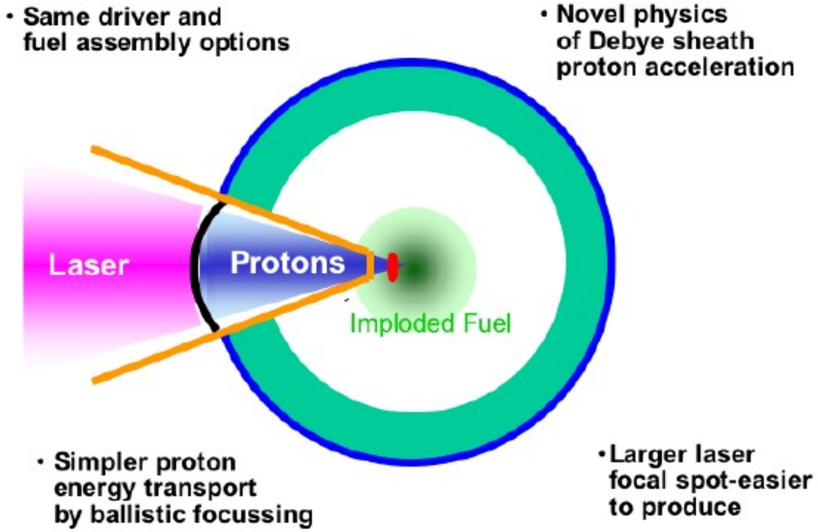
Compression and heating of the fuel is hard and ignition is challenging (but not impossible) because of instabilities and lack of symmetry





Cone guided proton fast ignition separates compression from heating, yields higher gain, smaller facility and is less sensitive to instabilities





We believe that there are a number of reasons why direct-drive PFI approach has advantages for IFE commercialization

Physics:

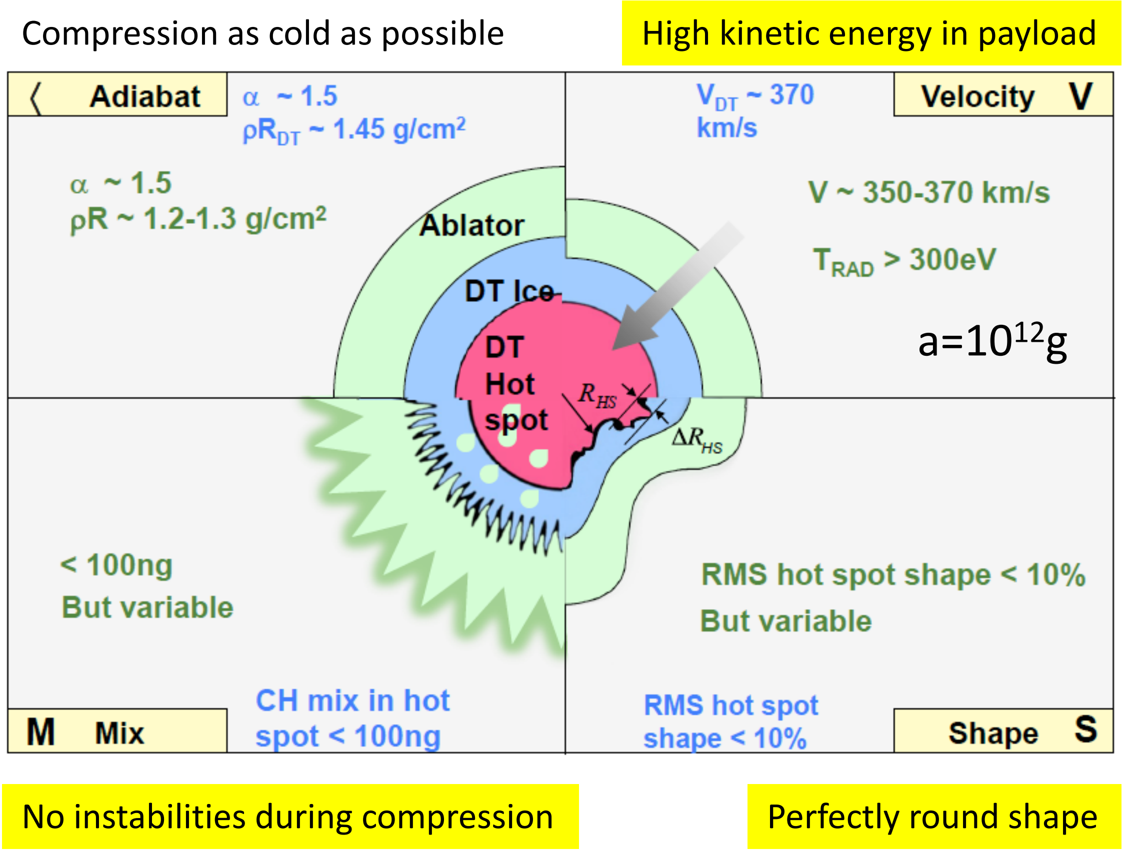
- 2ω direct drive reduces needed compression laser energy to ~ 400 kJ
- Proton ignition relaxes requirement of fuel assembly symmetry
- PFI permits lower compression drive laser intensity since no hot-spot need be formed, aiding in LPI mitigation

IFE Engineering

- Lack of hohlraum eases on-shot debris clearing problem at 10 Hz
- Cone in shell PFI target can act as shield for target as it is injected into a reactor chamber

Our approach has been chosen to try to address many of the unsolved problems in IFE

Four requirements for traditional hot spot ICF need to be fulfilled:

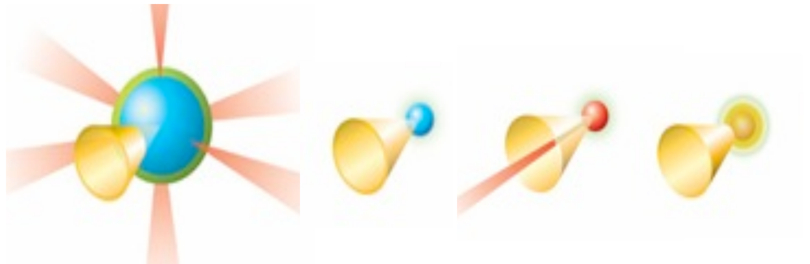


Growth rate:

acceleration

$$\xi = \xi_0 \exp(\gamma_0 t), \gamma_0 = \sqrt{Aka}, \quad A \equiv \frac{\rho_H - \rho_L}{\rho_H + \rho_L}, \quad k = \frac{2\pi}{\lambda}$$

Fast Ignition yields higher gain, smaller facility and is less sensitive to instabilities



- Less compression, less instabilities
  300g/cc vs. 1000g/cc; 100 km/s vs. 350 km/s; longer compression time
- Cold assembly of dense fuel
  less spherical symmetry required
- Larger fuel mass to burn
  thicker shell or even solid target, no low density hot spot
- Cone guided geometry
  shell protection for injection into reactor, double shell assembly, fueling
- Broader fuel choice possible
  hot spot energy constant, burn wave into low T or alternate fuel

The PFI approach is based on an extensive body of experimental and computation work

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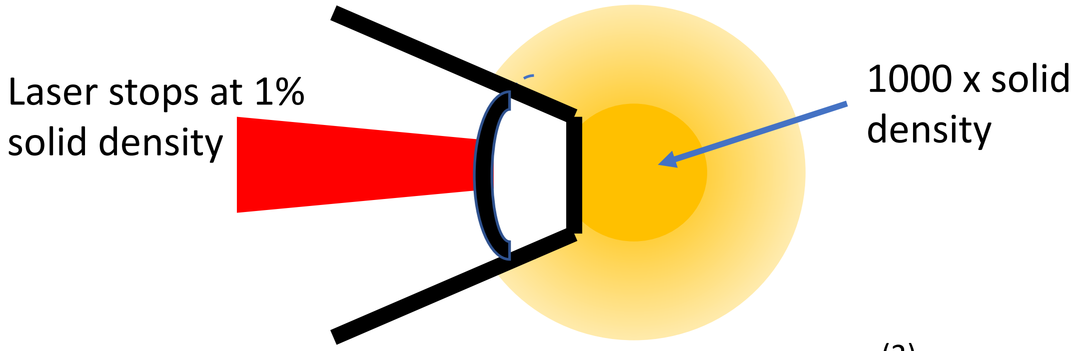
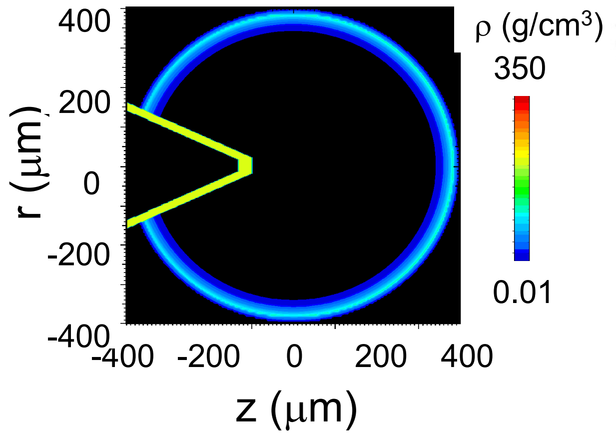
Challenge: Energy must be delivered to the dense fuel





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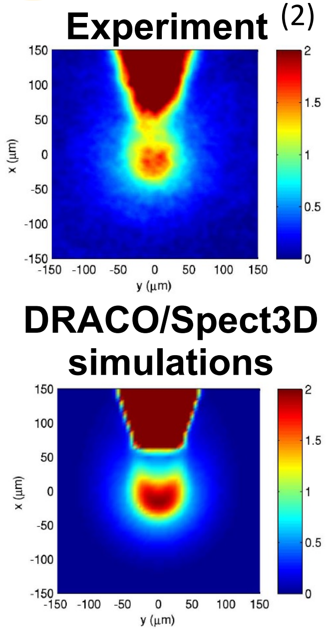
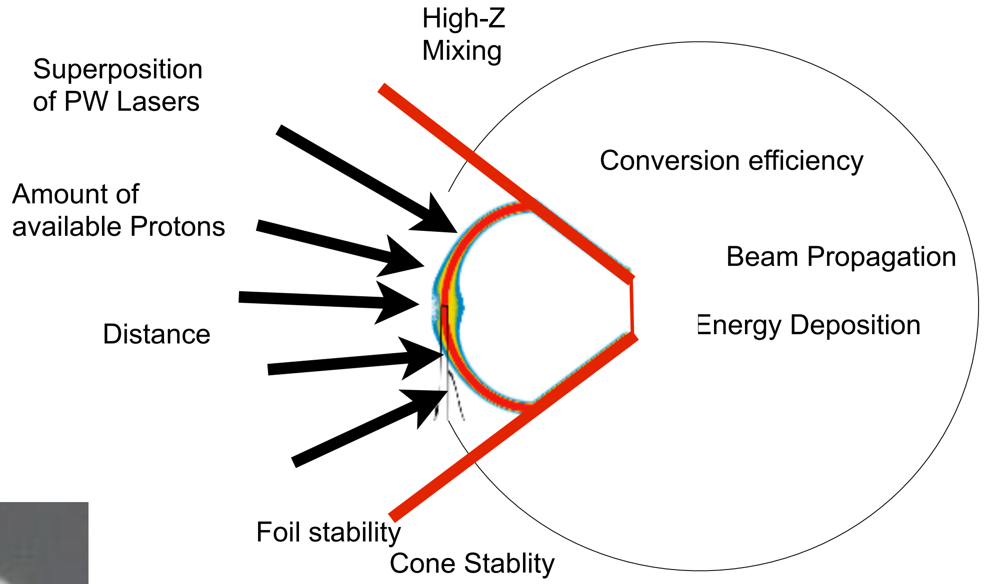
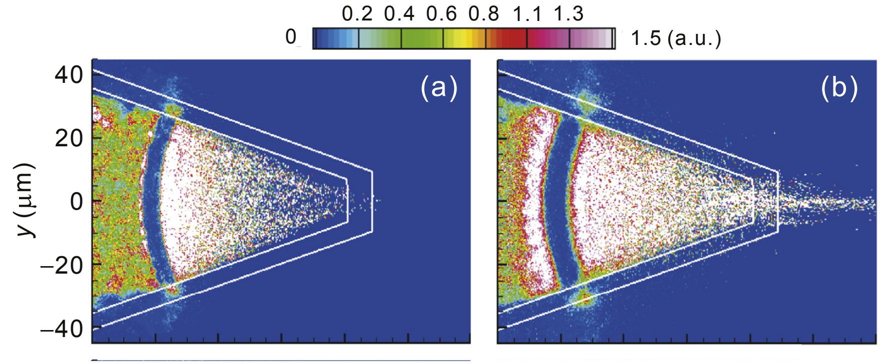


We have addressed the key topics in proton fast ignition





Energy density of the proton beam a) 1ps b) 1.5ps

[1]J.J. Honrubia et al., On intense proton beams and transport in hollow cones, Matter and Radiation at Extremes 2, 28, 2017

[2]W. Theobald et al., 54th Meeting APS-DPP, 2012

There is an excellent existing experimental and computational physics base for proton fast ignition

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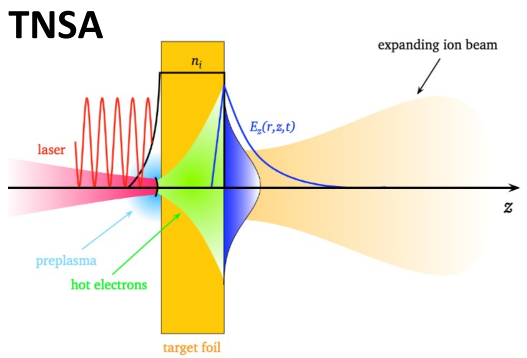
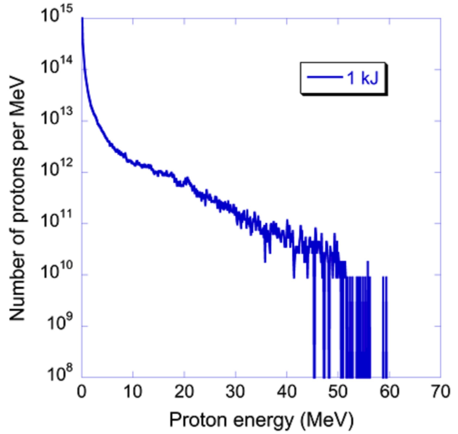
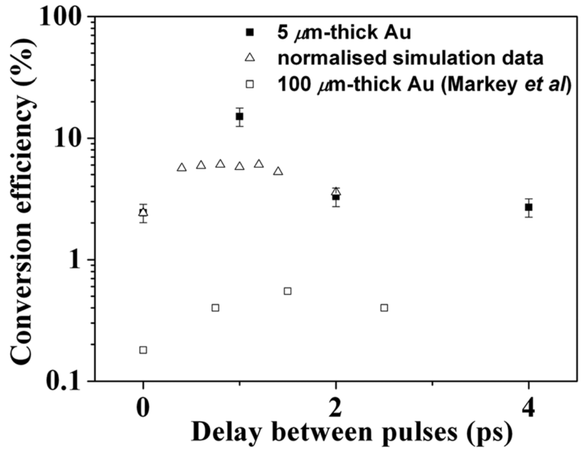
We can get the right ion energies



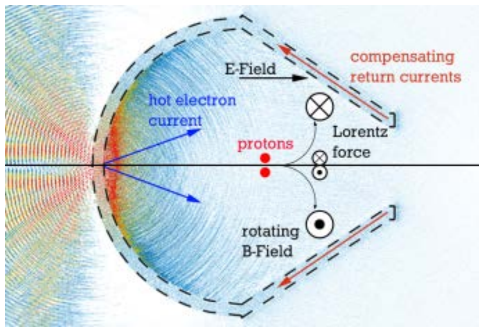


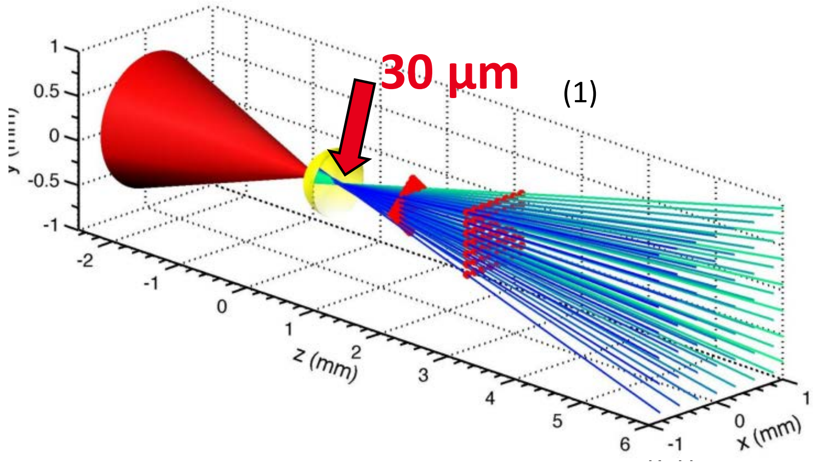
We can get a high conversion efficiency into the ion beam



(2)

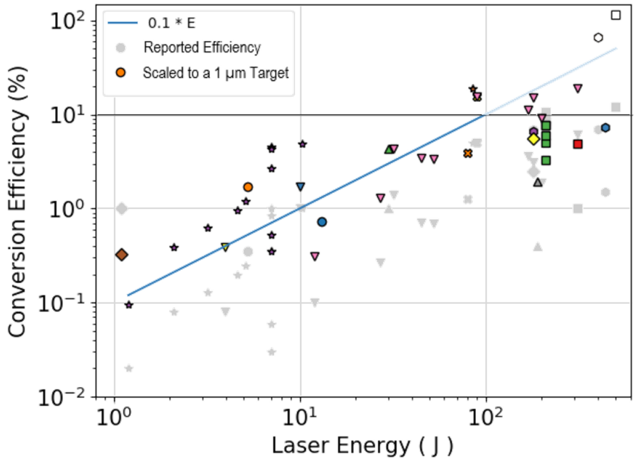
We can focus the beam





(1)

Ion beam generation scales favorably with laser energy



(3)

[1]T. Bartal et al., Focusing of short-pulse high-intensity laser-accelerated proton beams Nature Physics, DOI: 10-1038/NPYS2153

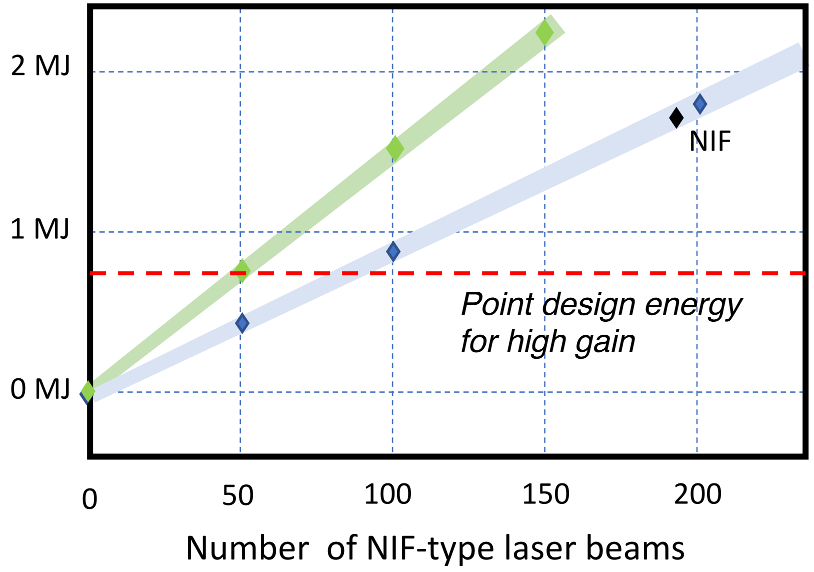
[2]C. Brenner et al., High energy conversion efficiency in laser-proton acceleration by controlling laser-energy deposition onto thin foil targets, Appl. Physics Letters 104, 081123 (2014)

[3]M. Zimmer et al., Analysis of Laser-Proton Acceleration Experiments for the Development of Empirical scaling Laws, Phys. Rev. E, submitted 2021

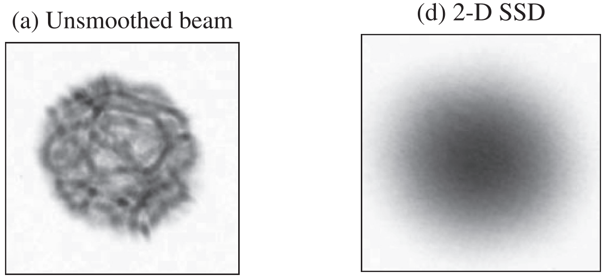
We believe that 2ω light for direct drive compression is a better route for IFE power plants than UV light

Direct-drive compression with green light

Less laser beams required



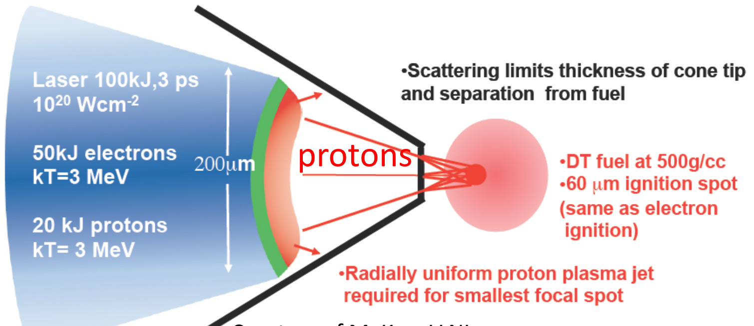
Green light allows for better beam control



- Will require LPI control
  - Laser bandwidth
  - STUD pulses (?)
- Fast ignition does not require high in-flight velocity so drive pulses can be lower intensity (~1 - 2 x 10^{14} W/cm^2)
- 527 nm light has higher damage threshold for optics than 351 nm
  - Frequency doubling can be done at the laser, not on the reactor chamber where neutron flux is high
  - Green light easily transported to chamber
- Frequency conversion can be slightly higher efficiency; broader bandwidth possible
- Requires fewer expensive large aperture nonlinear optical crystals

We have developed a detailed point design to demonstrate ignition with PFI

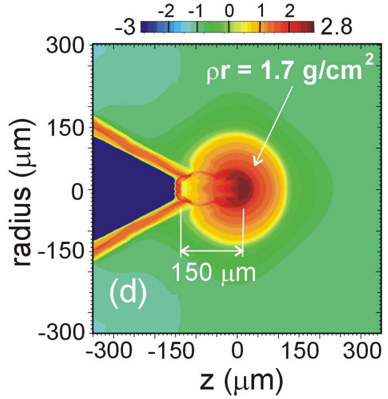
Design based on decades of research:
Lawrence Livermore National Lab.:

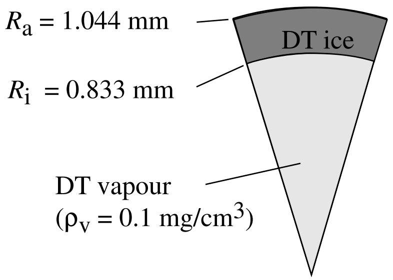


Courtesy of M. Key, LLNL

… and at HIPER:

HIPER: 2D rad-hydro Simulations (SARA)





Capsule:	**1.044 mm radius (inner), 1.050 (outer) CH or Be ablator**
Fuel:	**DT (50/50), solid or thick-wall shell (no ß-layering)**
Fill:	**0.587 mg DT**
Compression laser energy:	**280 kJ @ 2ω**
Max peak intensity:	**5×10^{14} W/cm^2**
RT growth factor :	**≤ 6**
Adiabat:	**~1**
Pulse duration:	**12 ns**
Fuel density:	**300 g/cc**
Max ρr (g/cm²):	**1.58**
max. fusion yield / gain:	**13 MJ / 30**

HIPER: 5 year EU design study on IFE-Fast ignition demonstration facility, > 100.
Publications, 26 institutions from 10 nations, endorsed by ESFRI

We have a good handle on what the first ignition target will be and what laser energy is needed to ignite it

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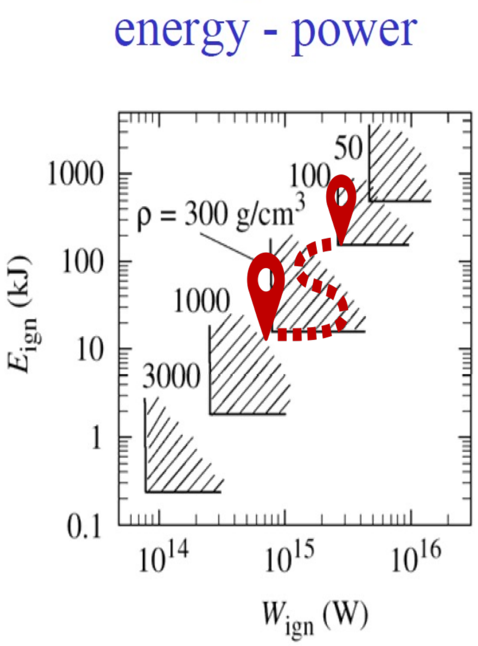
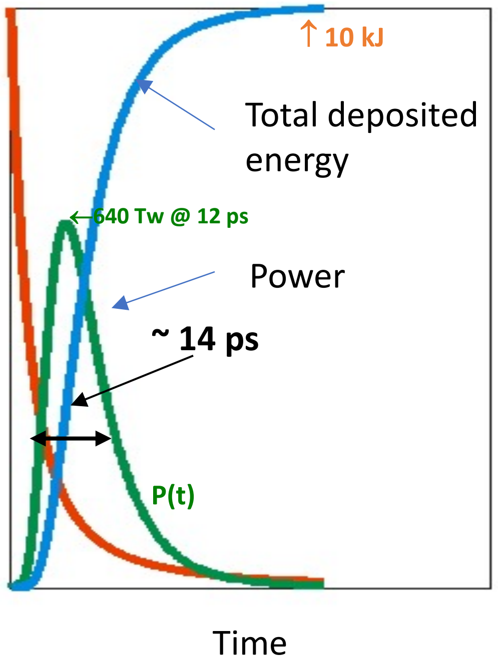
Proton beam energy:	**18 kJ**
T_{eff} proton beam:	**3.5 MeV**
Proton pulse duration:	**8 ps (gap closure)**
Proton focal spot size:	**50 µm**
Max. proton pulse duration:	**20ps (hot spot lifetime)**
Ignition laser:	**150 kJ @ 3 ps**
Ignition laser focal spot radius:	**350 µm**
Laser focusing optics:	**f/38 (approx. 15 m focal distance)**
cone material:	**50µm High-z (gold; Pb)**
tamping:	**possible cone wall tamping using Li or CH**
foil material:	**10µm (Cu; Al, Pb)**
cone tip:	**10 µm**
cone length hemi to tip:	**1mm**
cone length , opening angle:	**2mm, 60°**





Controlled nuclear fusion is VERY challenging with considerable technical hurdles and risks

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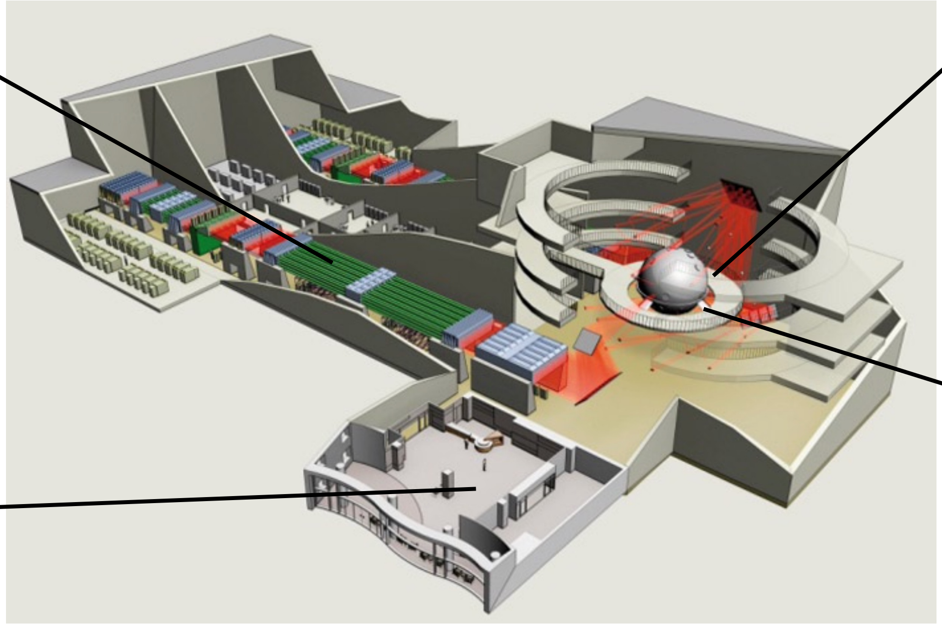
Technical Challenges to our IFE approach fall in four major categories

2) Laser development:

- *Can lasers those be manufactured economically?*
- *Can thermal management manage 10 Hz rep. rate?*
- *Can wall plug efficiency exceed >10%*

3) Target fabrication challenges:

- *Can targets be manufactured with necessary tolerances?*
- *Can >800,000 targets a day be made for < $0.50 per target?*



1) Inertial fusion physics challenge:

- *Is ignition possible within < 10 years?*
- *Is gain of over 100 possible?*
- *How much laser energy is needed for high gain?*
- *What is the best fusion fuel? (how much tritium?)*

4) Reactor chamber challenges:

- *Can the high neutron flux be handled?*
- *Do laser optics survive in this high radiation environment?*
- *What materials need to be developed to make the reactor vessel?*

5) Fifth risk area: Regulatory challenges of deploying IFE plants in various countries

We believe that we can assemble the broad expertise and experience in a team that can tackle these challenges on a 10 – 15 year time scale

We have developed a high-level roadmap for development and commercialization of IFE power with a 3 phase plan

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IFE Phase 1

- *Initial experiments on existing facilities*
- *Simulations to develop detailed fusion point design*
- *Conceptual and engineering design of test facility*
- *Conceptual design on demo plant*
- *Establish 3000 sq-meter laboratory*
- *Build test facility in collaboration with DOE at the University of Texas*

Spin out modular rep. rated laser technology

Secondary source technology development

- *Adapt IFE laser technologies to drive radiation sources*
- *Develop business and products*

IFE Phase 2

- *Build test facility for ignition: SUPER-NOVA*
- *Finish part of S-NOVA to do risk reduction experiments*
- *Conduct risk reduction experiments on proton acceleration and 2ω laser compression*
- *Demonstrate Ignition at modest gain (G~10) at S-NOVA*
- *Develop diode pumped module for QUASAR power plant demo*

Utilize laser and target fabrication technologies

Secondary source product commercialization

- *Develop rugged, industrial grade radiation source*
- *Enter markets*

Revenue generation from secondary laser sources

IFE Phase 3a

- *Build demo high gain power plant facility: QUASAR*
- *Work to demonstrate ignition at high gain (G~100)*
- *Develop detailed designs for energy production*
- *Demonstrate target production at 1 million/day*

IFE Phase 3b

- *Upgrade ignition facility with additional laser modules as needed to go to power plant-relevant gain (G~200)*
- *Work to demonstrate ignition at high gain (G~200)*

IFE Phase 3c

- *Upgrade ignition facility with tritium breeding technology*
- *Add power production to ignition chamber*

IFE Power plant deployment

We are undertaking a near-term science program to address critical risk areas

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Experimental efforts

1) Study of LPI and CBET effects in 2ω drive beams
   - Examine LPI in fast ignition relevant drive pulses (~ 10 ns @ ~ 10^{14} W/cm^2)
   - Examine effects of increased bandwidth
   - Explore possibility of STUD pulses for LPI mitigation

2) Study of proton acceleration efficiency
   - Examine scaling toward multi-kJ picosecond pulse drive
   - Examine pulse duration effects (with eye toward increasing pulse duration)
   - Examine effects of overlapping multiple picosecond beams on the acceleration foil

3) Iso-choric compression studies (hopefully on Omega)
   - Examine high ρ-R assembly with thick shells

Simulation efforts

1) Integrated fusion ignition simulation to confirm laser energy needs for SUPER-NOVA

2) Examine how to maximize ρ-R with thicker shells (or even uniform initial density DT ice)

3) Examine optimum beam arrangement for compression of cone-in-shell targets

In Phase 1, we plan to utilize a number of existing experimental facilities to reduce risk

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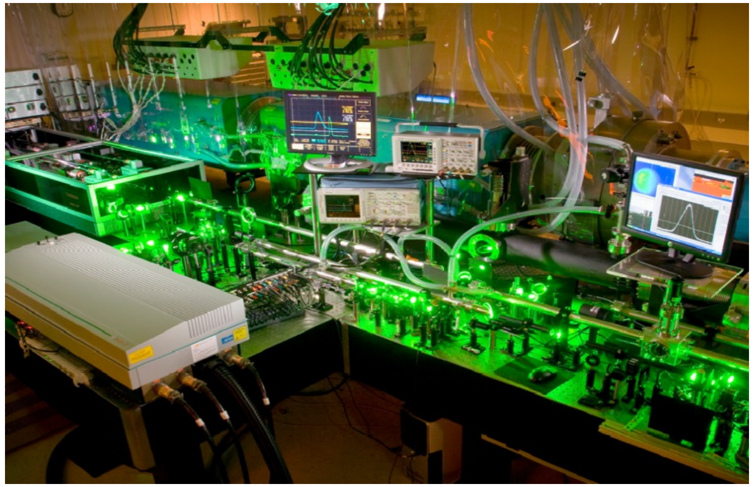
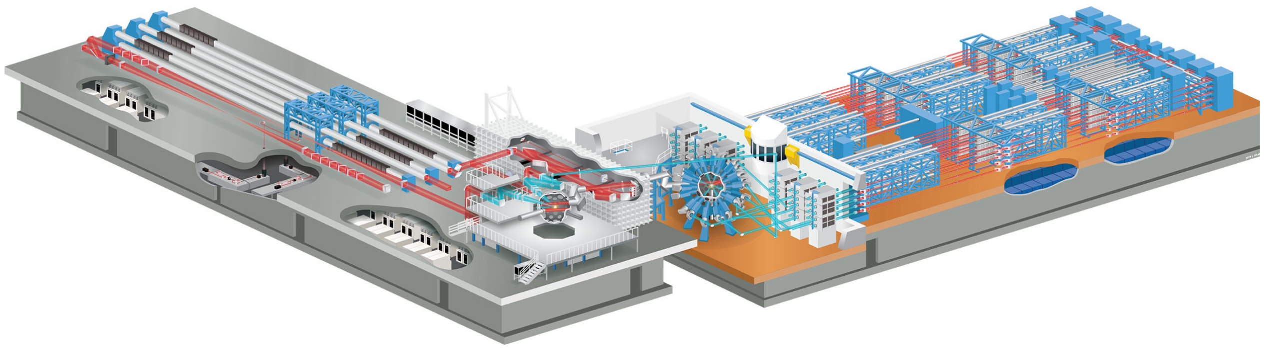
The L4 kJ picosecond laser at ELI-BL in Prague

The PHELIX laser at GSI Darmstadt

The Texas Petawatt laser at UT in Austin



The Omega laser at LLE Rochester



With significant input from our Advisory Committee, we have put together a 3 Phase facility development plan

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Facility	Location and Target completion	Targeted Specifications	Technical Goals
Mini-FEUER IFE Multi-purpose facility	University of Texas, Austin – Texas Petawatt High Bay lab **2024** Completion	4x beams @ 1 shot/min Each configurable in either long pulse (pulse shapeable) mode or short pulse CPA mode LP Mode: 4x 2 kJ @ 2ω (527 nm); 2- 15 ns shapeable SP Mode: 4x 1 kJ @ 1057 nm; 350 fs – 10 ps	• Study basic physics of FE Proton FI approach: 2ω drive; multi-PW proton beam production • Partner with DOE FES to develop dual use research facility available for peer-reviewed user access
Super-NOVA	Germany or Texas **2028** Completion	120x beams LP for direct drive compression @ 1 shot/min 400 kJ @ 2w (~10 ns) 60x beams CPA for proton accel. 150 kJ @ 1w (3 - 5 ps)	• Study integrated compression/proton heating (Super-NOVETTE) • Demonstrate Ignition at G~10 • Study gain scaling and optimum laser parameters
QUASAR	USA or Europe **2033** targeted completion	~250x Diode pumped laser modules @ 10 Hz 800 kJ (or more) LP @ 2w 150 kJ @ 3 ps	• Demonstrate facility operation at 10 Hz • Ignition gain up to G>200 • Demonstrate power production and tritium breeding

The technology needed for the test facility has already been developed and deployed by National Energetics in Prague

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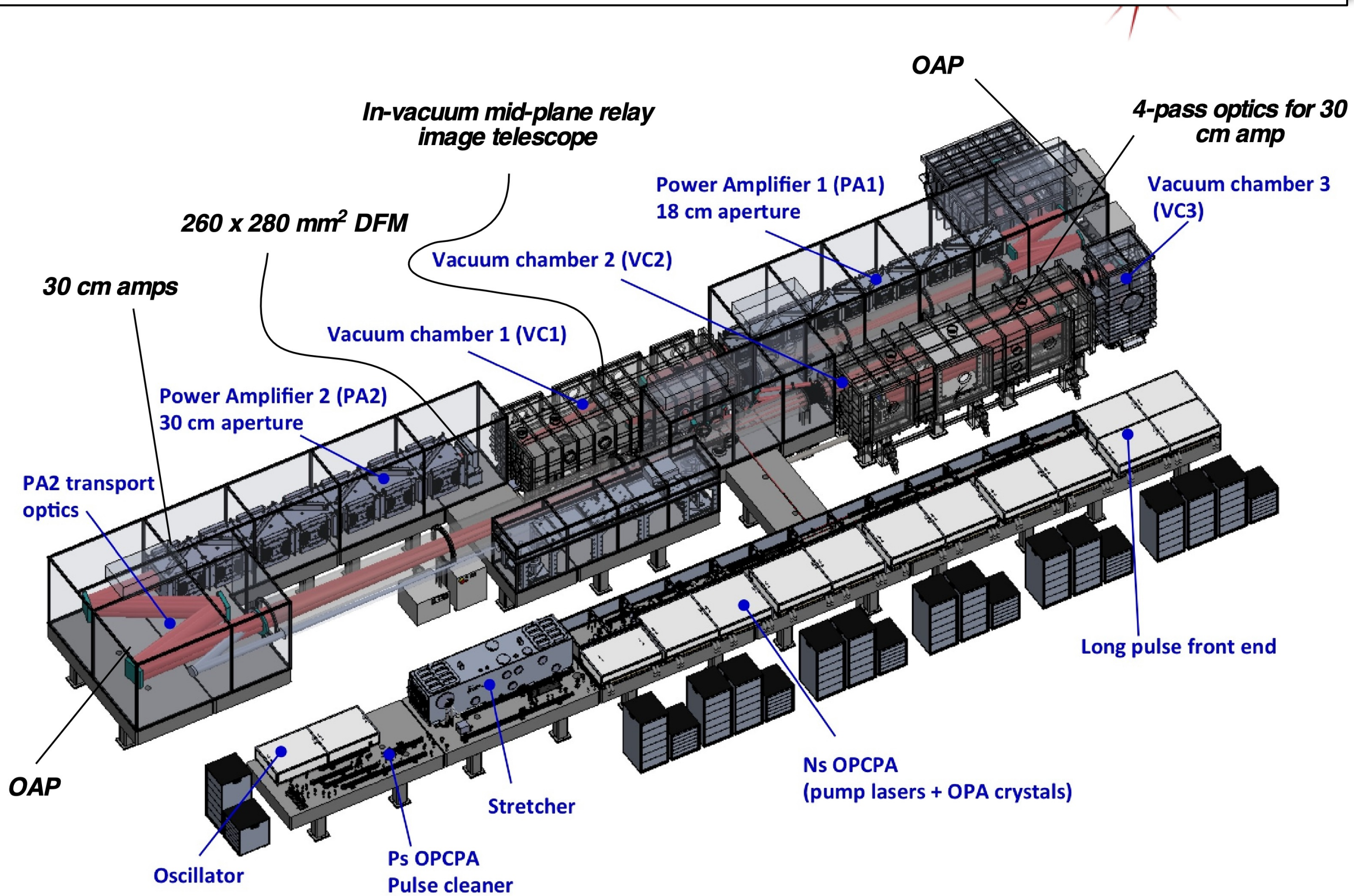
<u>L4 Laser</u>: 2 kJ per pulse
1 shot per minute
Pulse duration down to 135 fs



We are assessing the possibility of teaming with DOE FES and UT to build a joint, IFE research facility at the Texas Petawatt

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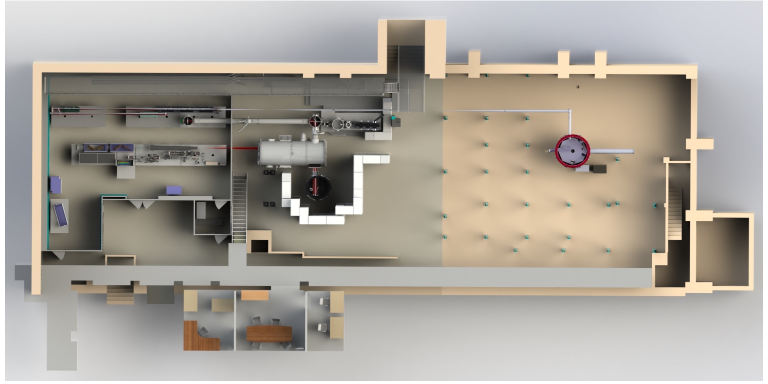
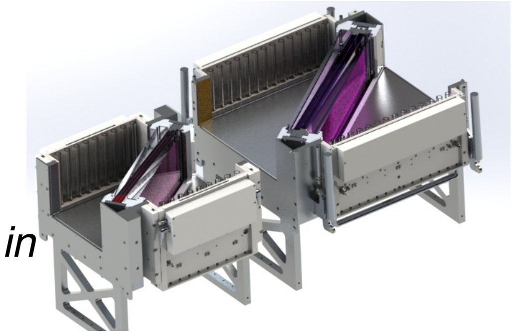
Prospective capability

- 4 beams firing @ 1 shot/min
  - Each can be operated in long pulse or fs-ps CPA mode
- LP Mode: 2 kJ per beam @ 527 nm
  - 2 – 15 ns, pulse shapeable
  - Broadband front end possible
- SP Mode: 1 kJ per beam
  - 350 fs – 10 ps
- 3 m diameter target chamber w/ flexible beam configurations

4 beam housed in expanded, 8000 sq. ft renovated high bay at UT in Austin



Power amplifiers are liquid-cooled, lamp pumped Nd:glass amps developed for L4 in ELI Beamlines



High Bay Renovations

*~ **$12M** renovation investment by UT (?)*

Facility Construction

*~ **$60M** construction investment by FE*

FE Experiments on IFE physics

- *50% usage by FE*
- *10% usage UT*
- *40% usage by outside users LaserNetUS or IFE Program peer review*

Operations DOE Funded (?)

2021 **2022** **2023** **2024** **2025** **2026**

We are beginning the design of a laser facility potentially capable of direct drive ignition with modest gain

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<u>SUPER-NOVA</u>

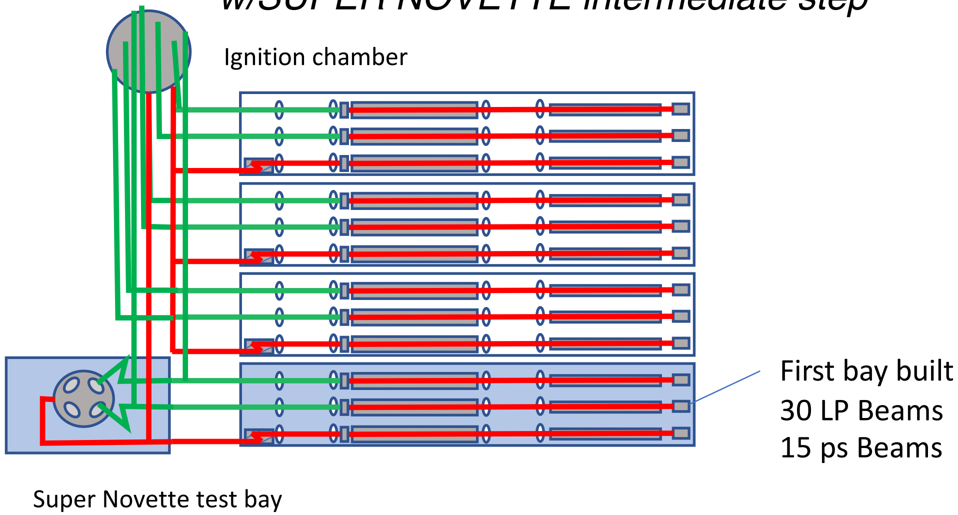
Ignition scale laser @ 1 shot/min
- *120 Compression beams*
  - *Each 3.5 kJ @2w ~ 10 ns*

- *60 CPA picosecond lasers*
  - *Each 2.5 kJ ~ 3 ps*

3m dia. S-NOVETTE Chamber

6 m dia. S-NOVA Ignition Test chamber

<u>SUPER-NOVA Concept</u>
w/SUPER NOVETTE intermediate step



Power amplifiers will utilize 30 cm liquid-cooled lamp-pumped Nd:glass technology, adapted from L4 technology ~ 3.5 kJ per beam @ 2w

Conceptual Design

Detailed Facility Design

Building construction

Long Lead procurements made

S-NOVA Facility construction

Complete first bay for initial experiments

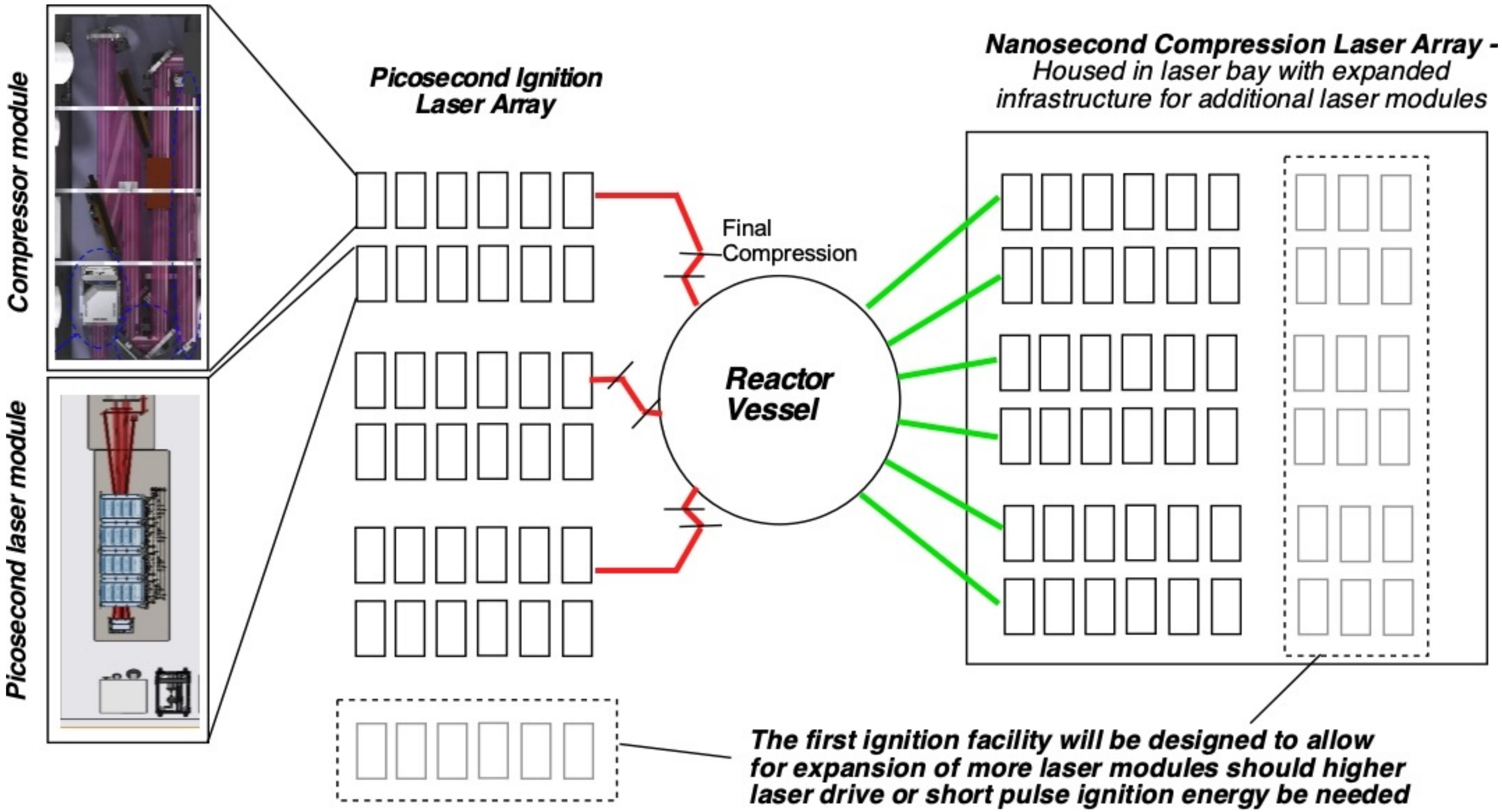
S-NOVETTE Operations and experiments

Operations and experiments

Ignition experiment

2021 2022 2023 2024 2025 2026 2027 2028 2029 2030

The QUASAR Fusion Test Reactor would be based on a concept designed with modular architecture to allow for expansion



A goal from the outset is to develop laser driver technologies that reduce cost and increase reliability by mass manufacturability

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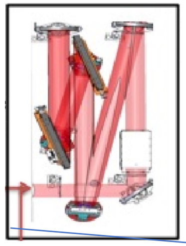
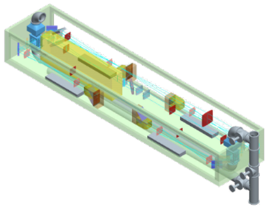
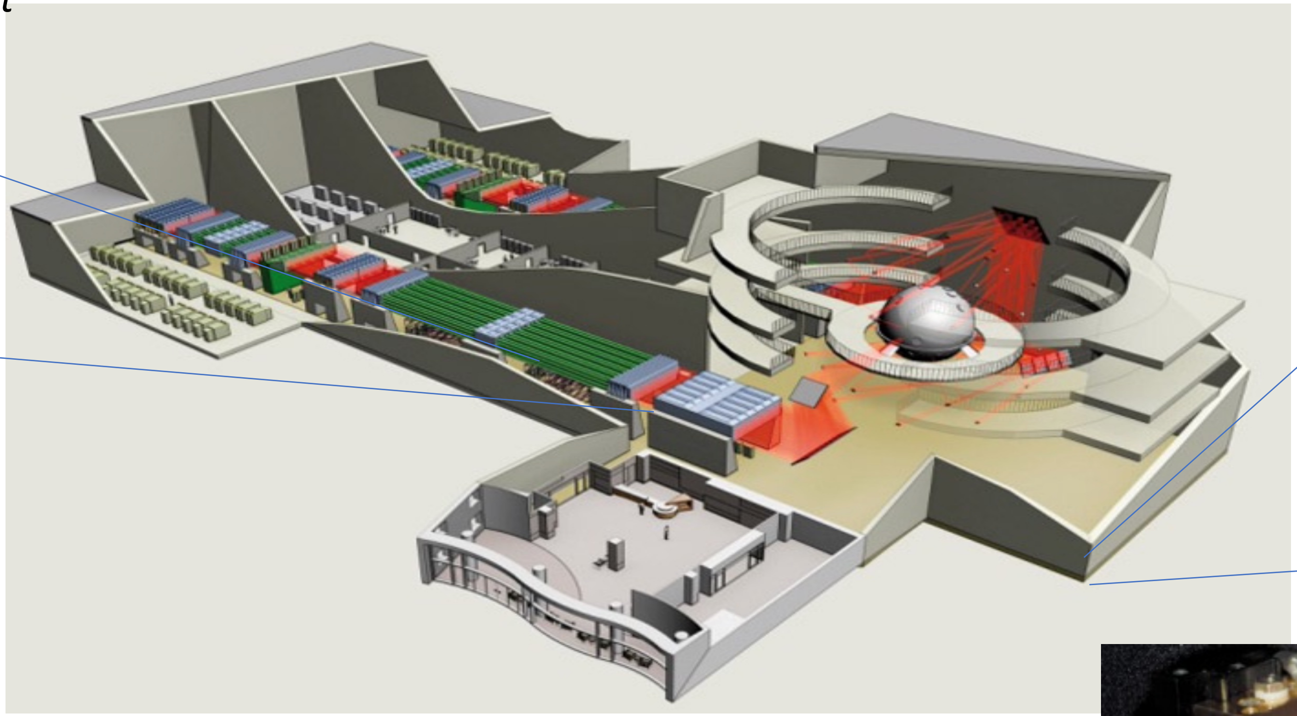
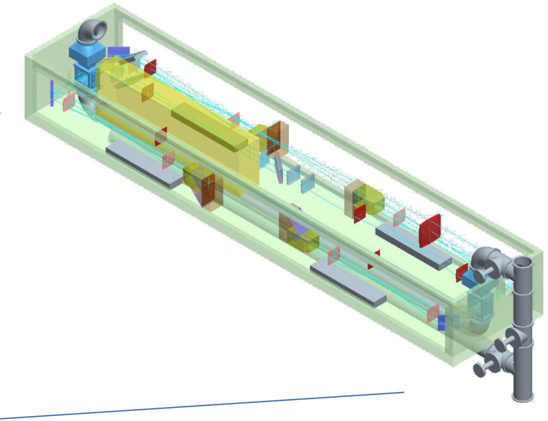
Modular Short pulse laser compressor units: ~1 kJ at 10 Hz.   100-200 units



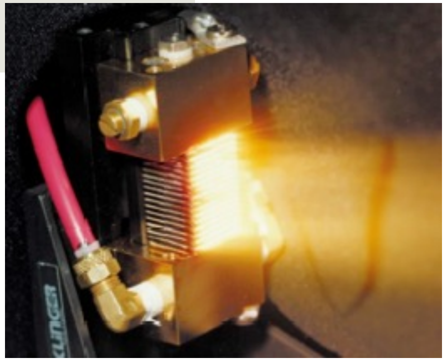


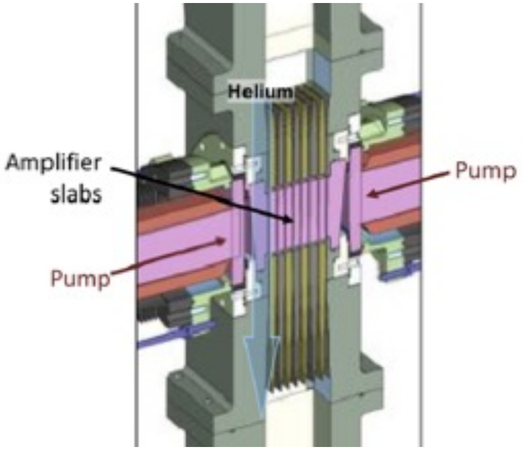


COMPRESSION LASER MODULES
Modular diode pumped laser: ~3 kJ at 527 nm out.   200-300 units



The QUASAR Demo power plant would require 200 – 300 individual diode pumped modular laser units





We are initiating an R&D effort to address the considerable challenges of inexpensive IFE target mass fabrication

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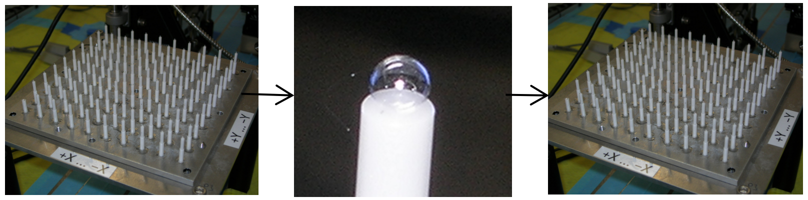
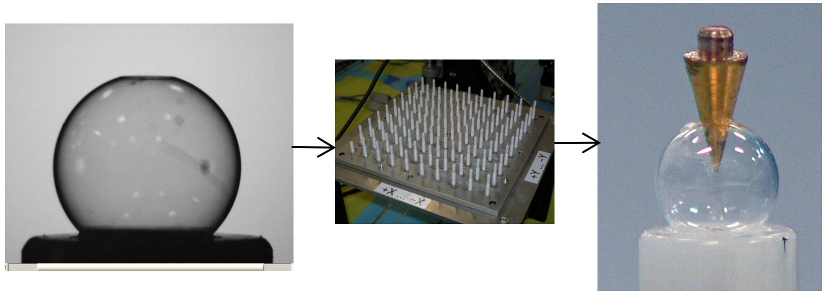
Target production for ~100/day



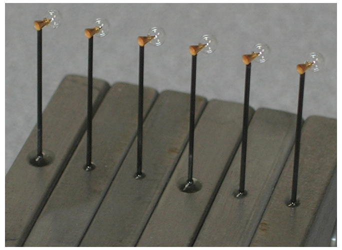
Glue capsules to handling posts (~90 min/batch of 100)



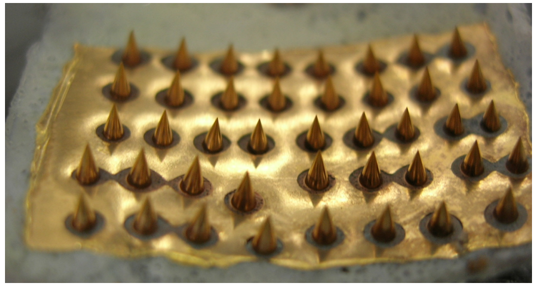
Cut holes in tops of capsules (~100/day)

Insert cone, align & glue (~120 min/batch of 100)

Mass production techniques for 3D components
Automated robot assembly of complex targets
Insertion of targets and tracking

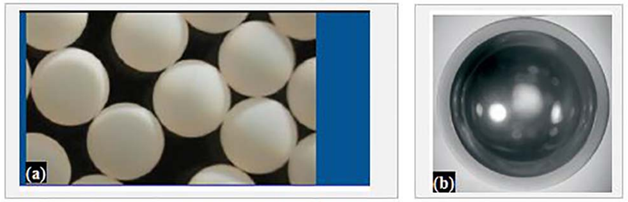


About 10^6 targets/day for <$1/target

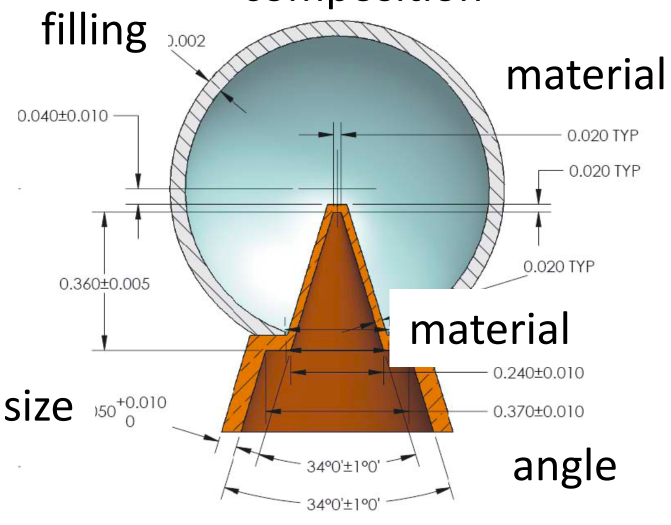


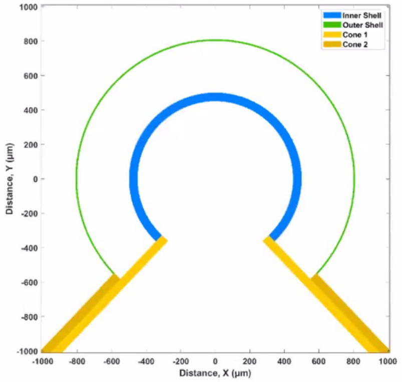
Stamp cones from metal

DVB shell targets unpolished/ polished



composition





We have identified some supply chain areas which will likely need investment to build capability

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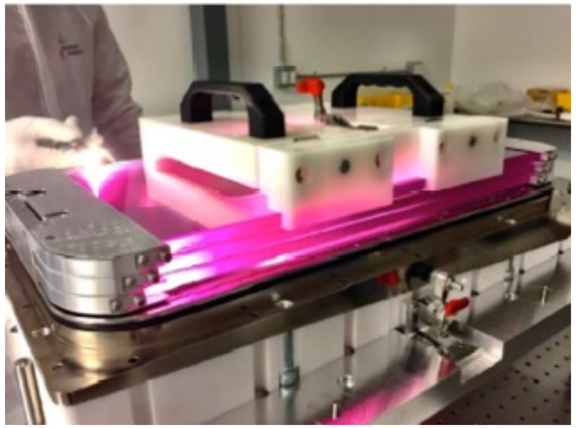
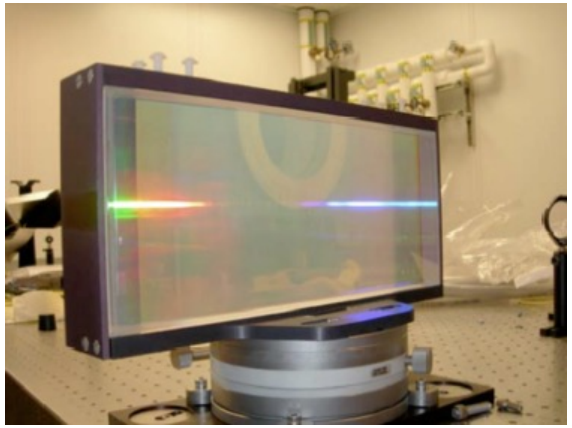


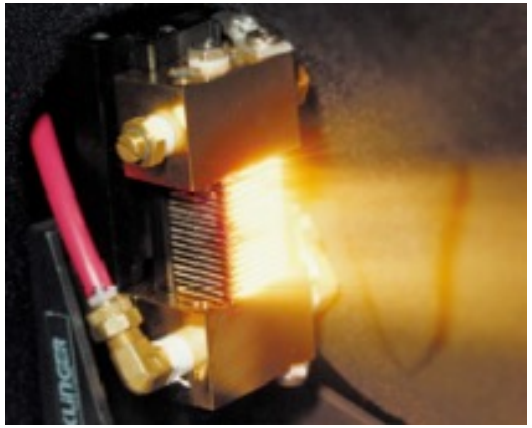
Laser amplifier glass

- Large slabs need for amplifiers
- 6000 – 10,000 slabs needed for SUPER NOVA alone (~$200M)
- Principal supplier is Schott (Germany) but they have reduced capacity since LLNL



Diffraction gratings

- Large aperture needed to compress multi-PW pulses
- 100 – 200 gratings needed for SUPER NOVA (~$50M)
- Principal supplier has been LLNL; some supply from PGL (USA) or Horiba (France)



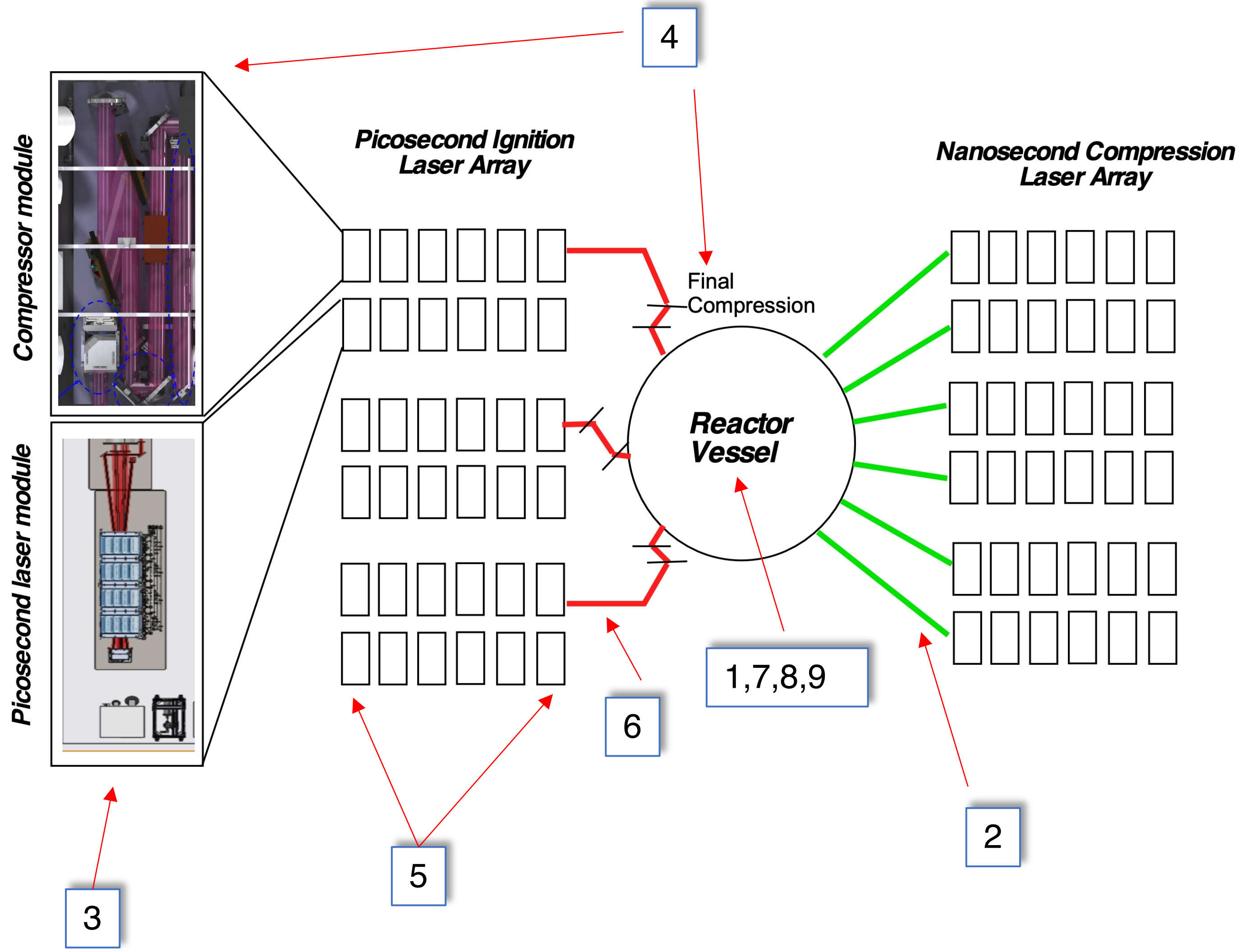
Laser Diodes

- 5 GW peak diode power needed to pump QUASAR
- At $0.10/watt are huge cost in power plant (~$500M)
- A number of suppliers in US and Germany, but none have mass production capability (with cost now ~$0.50/watt)

Integrated laser mass manufacturing

- 200 – 400 compact, rugid, manufacturable systems needed for QUASAR
- Will require manufacturing cost at <$1M/kJ laser energy
- Custom laser companies exist in US, France and Germany

Our IFE R&D plan is driven by the goal of demonstrating ignition and then building a 10 Hz demo reactor in the early 2030s



Areas needing innovation investment

1) High gain ignition concept

2) Compression using green (vs UV) laser light
   - *High efficiency conversion*

3) Modular diode-pumped driver laser
   - *Compact, rugged, inexpensive to manufacture*
   - *Wall plug efficiency >15%*

4) Picosecond compression technology
   - *Compression in gas, novel gratings (transmission gratings)*

5) Modular facility architecture with variable # of beams
   - *In-line replaceable modules*
   - *Picosecond and nanosecond laser module interchangeability*
   - *Architecture allowing plants with differing energy yields*

6) Beam transport
   - *Large stand-off of lasers; damage resistant, inexpensive optics; rugged to radiation damage*

7) Cryo target fabrication
   - Extremely inexpensive to manufacture rapidly

8) Target insertion at >10 Hz

9) Energy extraction and tritium breeding technologies
   - First wall materials need development

We have devised a phased path to commercial fusion power

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Phase 2: Ignition and burn

150 kJ ignition, 290 kJ compression

Yield: 13 MJ
Gain: 30

Ignition demonstrator: no electrical output

We will target a facility with 750 kJ ns lasers and 150 kJ ps lasers

2,1 mm
0.5 mg

Phase 3a: Demonstration of commercial gain

150 kJ ignition, 400 kJ compression

Yield: 38 MJ
Gain: 69

2,6 mm
1.1 mg

Phase 3c: Power plant

150 kJ ignition, 750 kJ compression

Yield: 165 MJ
Gain: 183

Output: 800 MW

4,0 mm
2.0 mg

We are working with our initial investors to secure the funding needing to realize ignition and a rep. rated power plant demo

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IFE Phase 1: Test facility and studies

IFE Phase 2: SUPER -NOVA facility. Ignition

IFE Phase 3a: QUASAR Diode-pumped power plant demo

IFE Phase 3b: High gain

IFE Phase 3c: Power demo

IFE Power plant deployment

First Raise round complete

Funds:
- Start up activities
- Renovation of Darmstadt R&D Lab facility
- Initial Engineering work on UT IFE Facility and SUPER-NOVA

Prime Movers Lab, Marc Lore, Alex Rodriguez

Prime Movers Lab

A-ROD CORP

Telosa

$15M — 2021

Verbal commitment from initial Investors

Funds:
- UT IFE Facility construction
- R&D on 10 Hz Diode pumped module
- Target fab
- SUPER-NOVA design

$150M — 2022

Funds:
- SUPER-NOVA building
- 3 kJ demo laser module @ 10 Hz
- QUASAR materials R&D
- QUASAR design

$500M — 2024

Funds:
- SUPER-NOVA construction
- SUPER-NOVETTE experiments
- Ignition demo

$2100M — 2026

Possibly funded in part by first utility customer

Funds:
- QUASAR demo @ 10 Hz
- Reactor and power production

$3000M — 2030

$5200M — 2035

2021 2022 2023 2024 2026 2028 2030 2035 2040

IFE Technology Summary: Our kick-off position in IFE is based on solid progress in all five challenge areas

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Major Challenge to an IFE Power Plant Demonstration	Where we are at this time	Major advancement needed for fusion reactor demonstration
Inertial fusion physics ignition and high gain	• Compression to necessary density demonstrated on NIF at 3ω • Proton conversion efficiency of ~10% demonstrated • Promising results seen on compression with 2ω green light	• Compression of isochoric fuel to ρR of >0.3 g/cm^2 with 2ω light • Demonstration of ~15% proton efficiency in high x-ray flux environment of imploded fuel • Combined ignition experiment
High repetition rate, high energy laser drivers	• 100 J-class 10 Hz lasers demonstrated • CPA at the multi-kJ level at 1 shot/min • Lasers are science machines in clean room labs	• Development of low cost, mass producible laser modules at ~3 kJ per pulse at 10 Hz • Development of compact, robust pulse compression modules
High throughput, high quality target fabrication	• Target types needed demonstrated at ~ 100 targets per day	• Target production at 10^6 targets per day at < \$0.50 per target • High reproducibility
Reactor chamber design, tritium breeding and energy harnessing	• Conceptual design for reactor and tritium breeding have been published • Some work on radiation resistant steel and fibrous reactor wall materials already conducted	• Reactor chamber that can hold up to GW level neutron fluxes for many years • Liquid lithium tritium breeding system • Easily replaceable inner reactor chamber
Fusion power plant regulations and licensing	• Discussions of regulatory framework in the US have been started with NRC by the Fusion Industry Association	• Framework for licensing a demo plant in the US with the NRC • Regulatory framework in Europe and Asia

IFE Science Summary: The science basis for proton fast ignition driven fusion gain is now very strong

- *Proton fast ignition decouples the compression of fusion fuel from the sparking of burn in the fusion fuel*
- *This eases the requirements for symmetry in compression*
- *There is good experimental evidence that compression can be achieved with 2ω green light, easing the manufacture of the drive lasers*
- *10% proton conversion efficiency has been demonstrated in select experiments, equaling what is needed for PFI*
- *We have a specific point design validated by multiple simulations*